The response of tropical cyclone activity to increasing CO2 in the Community Earth System Model

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Ongoing work supported by:

Blue Waters Symposium, Sunriver, Oregon, June 4, 2019
Tropical cyclones (e.g. hurricanes) pose serious risks

Katrina, 2005

Harvey, 2017

Tied for costliest hurricanes on record
$125 Billion each (2017 USD)

Understanding connections between tropical cyclones and climate is critical for coastal planning and flood risk assessments
How will TCs change in the future?

Downscaling CMIP5 climate models shows increased tropical cyclone activity over the 21st century

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Emanuel, 2013

The question is difficult to answer with global models due to coarse resolution and lack of ocean-atmosphere coupling

Walsh et al., 2015
Impact of surface coupling grids on tropical cyclone extremes in high-resolution atmospheric simulations

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Projected changes in tropical cyclone activity under future warming scenarios using a high-resolution climate model

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Our approach to the TC-Climate problem:
Hierarchical experiment using high-resolution configurations of CESM to analyze TC-climate relationship

Why Blue Waters?
- Model version adapted from other groups — Susan Bates (NCAR) and Don Wuebbles (UIUC)
- CESM scales well on Blue Waters to ~15,000 cores
  - Extensive load balancing (Hui Li) to optimize cost

Major Challenge: Analyzing weather in a climate model
- Fine spatial resolution (0.25 deg atm, ~1 deg ocean)
- Coupling ocean and atmosphere (scale mismatch)
- Integration length (multi-decadal simulations)
- High frequency IO (sub daily model outputs)
- Post-processing (analyzing and visualizing the results)
42 years pre-industrial (Li et al., 2018 JAMES)

Impact of air-sea coupling

Sensitivity to CO2

Experimental Design:

- Fully coupled
  - Atmosphere CAM5 SE 0.25° grid
  - Ocean POP2 1° grid
- Fully coupled 4xCo2
- Fully coupled continue
  - Atmos-only
  - Atmosphere CAM5 SE 0.25° grid

42 years pre-industrial

2015

2017

2019

Total Cost:
- 40 million core hours (with extensive load balancing)

Total Size:
- 100 TB (includes monthly daily, and sub daily fields)
Data is available on NCAR’s Climate Data Gateway:
https://www.earthsystemgrid.org

Climate Data at the National Center for Atmospheric Research
Find and download climate data and analysis tools

Example: Search term — TC

6-hourly variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Unit</th>
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<tbody>
<tr>
<td>T300</td>
<td>Temperature at 300 mbar pressure surface</td>
<td>K</td>
</tr>
<tr>
<td>T500</td>
<td>Temperature at 500 mbar pressure surface</td>
<td>K</td>
</tr>
<tr>
<td>TBOT</td>
<td>Lowest model level temperature</td>
<td>K</td>
</tr>
<tr>
<td>U10</td>
<td>10m wind speed</td>
<td>m/s</td>
</tr>
<tr>
<td>U850</td>
<td>Zonal wind at 850 mbar pressure surface</td>
<td>m/s</td>
</tr>
<tr>
<td>UBOT</td>
<td>Lowest model level zonal wind</td>
<td>m/s</td>
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<tr>
<td>V850</td>
<td>Meridional wind at 850 mbar pressure surface</td>
<td>m/s</td>
</tr>
<tr>
<td>VBOT</td>
<td>Lowest model level meridional wind</td>
<td>m/s</td>
</tr>
</tbody>
</table>

Special thanks to Susan Bates and Gary Strand at NCAR
Some recent highlights and products:

**TC Impacts on the Ocean**


**TCs in Coupled vs Atmosphere-Only Simulations**


**Response in TC activity to CO2**

- Work in Progress
**Impact of TCs on the Ocean**

- Tropical cyclones tend to cool the surface ocean primarily by vertical ocean mixing
- TC-induced mixing redistributes heat vertically in ocean column leading to subsurface warming

**Hurricane Gert, 1999**

What happens to the subsurface heat? Does TC-mixing contribute to heat and energy budgets? What is the effect on large-scale variability?
Animations for visualizing TC-ocean interactions in CESM using Blue Waters

Produced by David Bock and Rob Sisneros
National Center for Supercomputing Applications (NCSA)
Data Analytics and Visualization

http://manabe.atmos.uiuc.edu/~rsriver/Bock_Climate_SC_revised.mp4

Li and Sriver, 2016 — JGR Oceans
TCs in coupled ocean-atmosphere and atmosphere-only simulations

- CESM generally reproduces observed TC activity (locations, intensity, seasonality)

- More intense storms in atmosphere-only simulation (no ocean mixing!)

Li and Sriver, 2018; Li and Sriver, 2019
- Coupled CESM simulates 27% less major TCs
  - Decreased power dissipation and equatorward shift in peak intensity

- Ocean-Atmosphere interactions can modulate TC intensity, evolution, activity and variability
  - Models with fixed ocean conditions are missing these feedbacks
Response in TC activity to increased CO2

4xCO2 Simulation:
- Branched from coupled control
- Instantaneous quadrupling of atmospheric CO2
- 30-year simulation
- Compare TC stats and anomalies with control run

Questions:
- How does TC activity change under extreme radiative forcing?
- Can we learn something about environmental factors controlling TC activity?
Response in TC activity to increased CO2

TC Track Density

Under 4xCO2 conditions:
- Decrease in storm counts
- Increase in storm intensity

Why?
- Tradeoffs between enhanced vertical wind shear and increased SST
Ongoing Work:

- Compare/Contrast CESM results with downscaling methods (cf. Emanuel, 2013)
- Preliminary results indicate similar sensitivity to interactive ocean mixing
- Downscaling provides thousands more TC tracks, but lacks physical consistency in CESM

Future Directions:

- Combine numerical/statistical models to examine factors influencing TC changes and variability
- Deep-learning could be very useful due to data size, multi-scale interactions, and non-linear relationships
- Probabilistic TC projections for coastal flood risk assessment
Some Conclusions:

- We conducted a series of multi-decadal CESM simulations examining the relationship between TC-climate interactions.

- Ocean-Atmosphere coupling significantly influences TC activity and the feedbacks could be important for large-scale ocean and atmosphere energy budgets and circulations.

- Increasing CO2 leads to reduction in overall number of storms while increasing intensity of most intense storms.
Extra Slides
TC structure in high-res CESM

25 km ATM

What the ocean sees

Li and Sriver, 2016 - JGR-Oceans
Some recent results

- Both coupled and uncoupled versions of CESM simulate realistic spatial patterns and key features of the annual cycle.

CESM (Fully-Coupled)

CESM (Atm-Only)

Li and Sriver (2018) — Journal of Advances in Modeling Earth Systems